

Composite Pressure Vessel Variability in Geometry and Filament Winding Model

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Abstract

Composite pressure vessels (CPVs) are used in a variety of applications ranging from carbon dioxide canisters for paintball guns to life support and pressurant storage on the International Space Station. With widespread use, it is important to be able to evaluate the effect of variability on structural performance. Data analysis was completed on CPVs to determine the amount of variation that occurs among the same type of CPV, and a filament winding routine was developed to facilitate study of the effect of manufacturing variation on structural response.

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Introduction

Currently there are many finite element analysis (FEA) codes available that can be used to model pressure vessels including Genoa PFA^{®1}, ABAQUS^{®2}, and Salome^{®3}. [1] The focus of this study was to measure variability in manufactured composite pressure vessels (CPVs) and to develop an approach to evaluate the effect of variation on the modeling process. For this purpose, measurements were made on CPVs, a filament winding model was developed, and hoop and helical model results have been plotted.

Software

Red Hat^{®4} Enterprise Linux^{®5} and CAE Linux 2011 were used to do the modeling and perform the analysis. The filament winding model was written in Octave, an open source tool similar to Matlab^{®6}. Modeling was also done using Genoa, Salome, and in NASA's ICAN code. [2]

Data Analysis

The current practice in the CPV industry is to build a single mathematical stress analysis model for all vessels of a specific design or model number. This project has taken some first steps to evaluate if the practice of using one stress analysis model for a CPV design is reasonable.

Data was collected and analyzed on CPVs for parameters that affect geometry, and thus model to part accuracy. It was observed that length and circumference could be two to three standard deviations from mean measurement values for CPVs of the same design. This variability in geometry was greater than expected and was a consideration in the design of the mathematical filament winding model.

Mathematical Filament Winding Model

After data analysis was completed, a mathematical filament winding model was built to study the effect of geometrical variation on structural response. The model, "sjgreenwrap," was developed in Octave as an element winding code similar to the theory presented by Sotiris Koussios. [3] The code has a main program and four subroutines: a hoop wind, a helical wind, a unit vector module, and a transformation matrix module. The parameters for each CPV can be input into the model and then output files can be saved for comparison of filament winding properties. Figure 1 shows a flow chart for the program.

¹ Genoa PFA[®] is a registered trademark of Alpha STAR Corporation, Long Beach, CA.

² ABAQUS[®] is registered trademark of ABAQUS, Inc., Pawtucket, RI.

³ Salome[®] is a registered trademark of Open CASCADE, Paris, France.

⁴ Red Hat[®] is a registered trademark of Red Hat Inc., Raleigh, NC.

⁵ Linux[®] is a registered trademark of Linux Mark Institute, San Francisco, CA.

⁶ Matlab[®] is a registered trademark of The Mathworks Inc., Natick, MA.

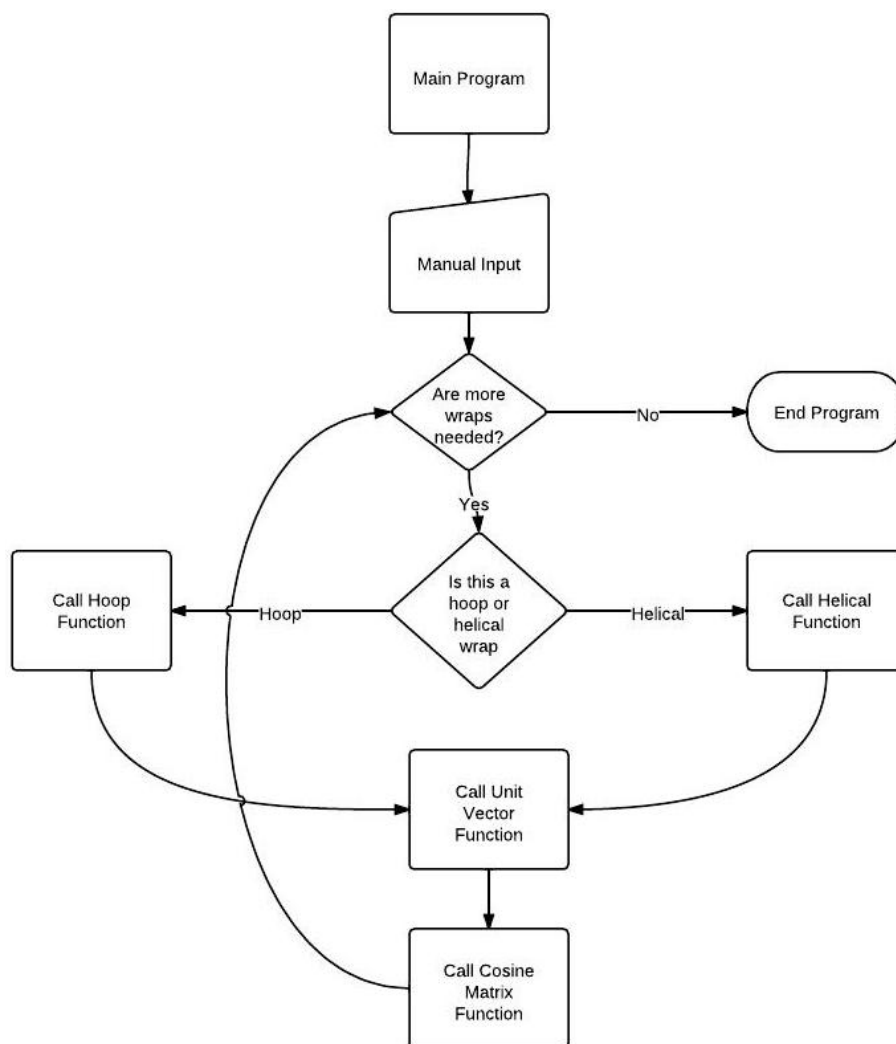


Figure 1
Filament Winding Model Flow Chart

The main code begins by requesting information about CPV geometry: the height of the cylinder section, the radius of the cylinder section, and the radius of the neck of the boss. The program also has input lines for tow width, the number of wraps, and the number of helicals.

From the inputs, the main program builds the model and returns x, y, and z values in an inertial reference frame and returns a unit vector for each point along the fiber indicating fiber direction. The program outputs are in two dimensional matrices and three dimensional plots. Figures 2 through 4 show the output plot of a helical wrap, hoop wrap, and a combination of the two wraps.

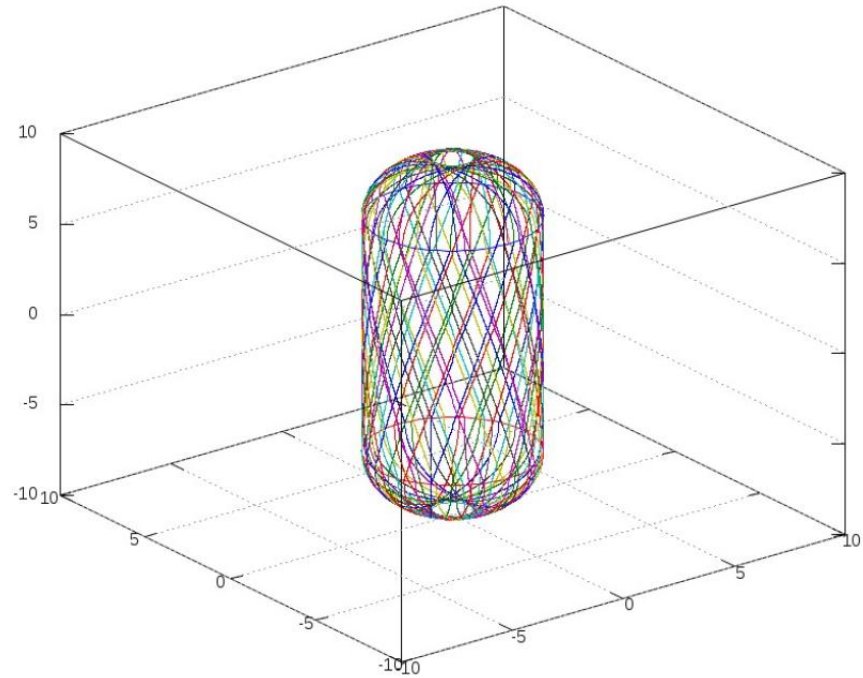


Figure 2
Helical Wrap

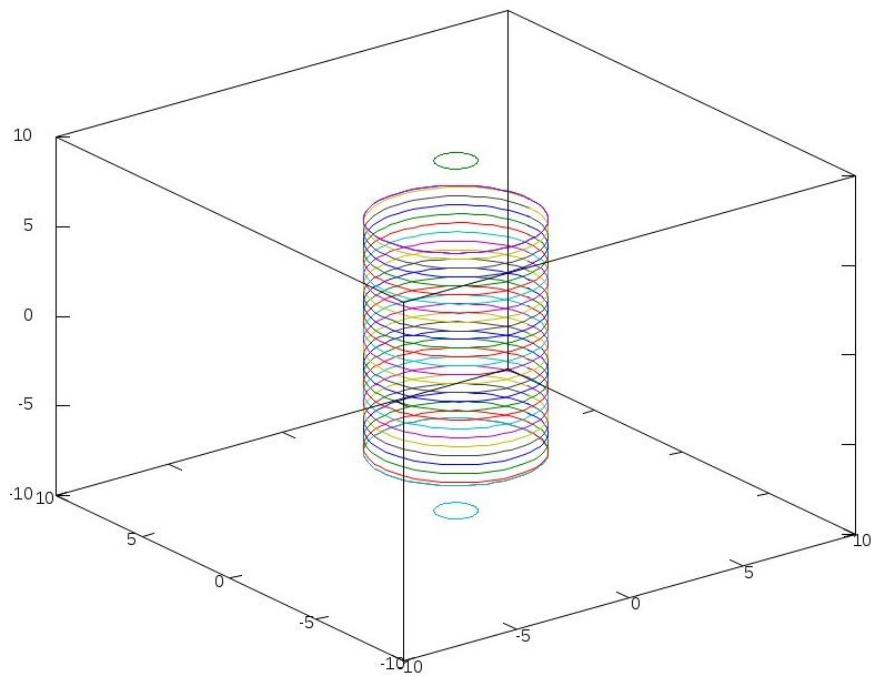


Figure 3
Hoop Wrap

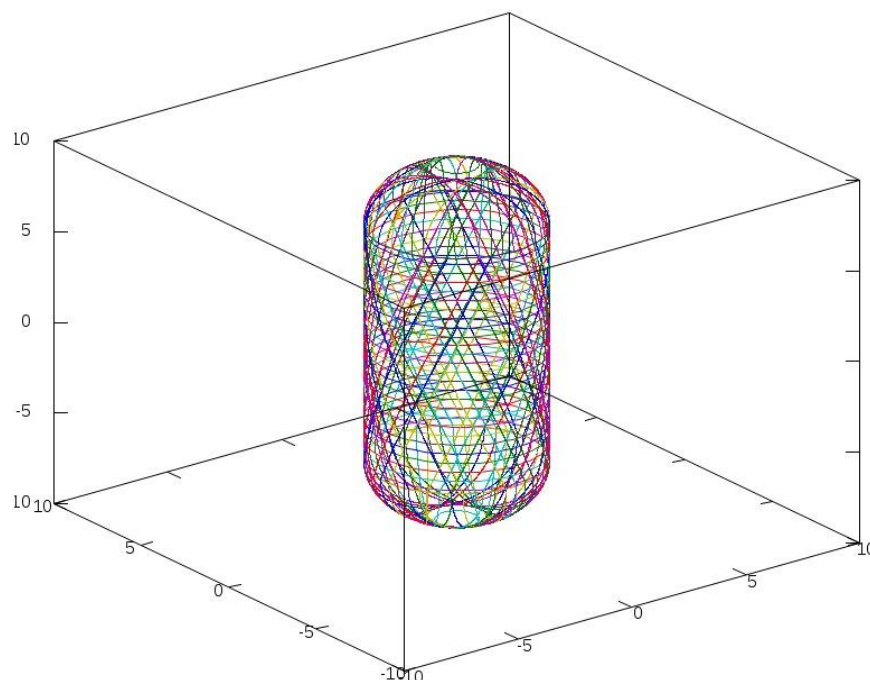


Figure 4
Combination of Helical and Hoop Wraps

Conclusion

The project has been successful in analyzing measurements and building a filament winding model to evaluate geometrical variation. A disconnect has been observed between CPV geometrical variation and the standard practice of using a single model to estimate structural response. The significance of the observed difference between models and CPVs is unclear.

There is a drive in industry to lower factors-of-safety (FOS) for CPVs. Preliminary research conducted in this study suggests that additional work should be done to determine how critical the observed disconnect in structural modeling is for new designs. The amount of variation becomes increasingly critical in the assessment of reliability as the FOS is reduced.

Reference

- [1] Sanchez, C. *Evaluation of Progressive Failure Analysis and Modeling of Impact Damage in Composite Pressure Vessels*. USRP Report. NASA JSC White Sands Test Facility, Las Cruces, NM, July 31, 2011.
- [2] Torres, J. *Composite Damage Evaluation and Development of A Graphical User Interface for a Composite Micromechanical Modeling Code Using Open Source Tools*. USRP Report. NASA JSC White Sands Test Facility, Las Cruces, NM, Publication in progress.
- [3] Koussios, S. *Filament Winding: a Unified Approach*. The Netherlands: DUP Science, 2004.